VERIFICATION OF TRANSLATION

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[LIST OF ATTACHED DOCUMENTS]
[ITEM] SPECIFICATION 1
[ITEM] DRAWINGS 1
[ITEM] ABSTRACT 1

[Type of Document] Specification

[Title of the Invention] Starting Device for Internal Combustion Engine

[Scope of Claims for Patent]

[Claim 1] A starting device for an internal combustion engine that ignites fuel supplied in an expansion-stroke-cylinder of the internal combustion engine to start the internal combustion engine, comprising:

a predicting unit that predicts a state of a crank when the expansion-stroke-cylinder is ignited, before a starter is started; and

a determining unit that determines whether to start the starter based on the state of the crank predicted.

[Claim 2] The starting device for the internal combustion engine according to claim 1, wherein

the predicting unit predicts a state of the crank before a first ignition is performed in the expansion-stroke-cylinder, and

the determining unit determines whether the starter is to be started before the first ignition is performed in the expansion-stroke-cylinder.

[Claim 3] The starting device for the internal combustion engine according to claim 1 or 2, wherein the predicting unit estimates the state of the crank based on a stop position of the crank and a water temperature in the internal combustion engine.

[Claim 4] The starting device for the internal combustion engine according to any one of claims 1 to 3, wherein the predicting unit estimates combustion power produced if the fuel in the expansion-stroke-cylinder is ignited, and predicts the state of the crank

based on the combustion power estimated.

[Claim 5] The starting device for the internal combustion engine according to claim 4, wherein the predicting unit estimates an amount of oxygen in the expansion-stroke-cylinder and estimates the combustion power based on the amount of oxygen estimated.

[Claim 6] The starting device for the internal combustion engine according to claim 5, wherein the predicting unit estimates the amount of oxygen based on a stop position of the crank corresponding to air capacity in the expansion-stroke-cylinder.

[Claim 7] The starting device for the internal combustion engine according to claim 5 or 6, wherein the predicting unit estimates air density in the expansion-stroke-cylinder, and estimates the amount of oxygen based on the air density estimated.

[Claim 8] The starting device for the internal combustion engine according to claim 7, wherein the predicting unit estimates the air density based on a water temperature in the internal combustion engine.

[Claim 9] The starting device for the internal combustion engine according to any one of claims 4 to 8, wherein the predicting unit estimates frictional force produced if the fuel in the expansion-stroke-cylinder is ignited, and predicts the state of the crank based on both the frictional force estimated and the combustion power estimated.

[Claim 10] The starting device for the internal combustion engine according to claim 9, wherein the predicting unit estimates the

frictional force based on friction produced when the crank rotates and a compression work in a follower cylinder that follows the expansion-stroke-cylinder.

[Claim 11] The starting device for the internal combustion engine according to claim 10, wherein the predicting unit estimates the frictional force based on a stop position of the crank that corresponds to the compression work in the follower cylinder.

[Claim 12] The starting device for the internal combustion engine according to claim 10 or 11, wherein the predicting unit estimates oil viscosity corresponding to the friction, and estimates the frictional force based on the oil viscosity estimated.

[Claim 13] The starting device for the internal combustion engine according to claim 12, wherein the predicting unit estimates the oil viscosity based on a water temperature in the internal combustion engine.

[Claim 14] The starting device for the internal combustion engine according to any one of claims 1 to 13, wherein the state of the crank is either of a rotational angle of the crank or a number of revolutions of the internal combustion engine.

[Claim 15] The starting device for the internal combustion engine according to any one of claims 1 to 14, wherein the starter is started after the fuel in the expansion-stroke-cylinder has been ignited.

[Claim 16] The starting device for the internal combustion engine according to any one of claims 1 to 15, wherein the starter is started at a timing such that the starter and the internal combustion

engine get coupled to each other when the crank is in a state of acceleration.

[Claim 17] The starting device for the internal combustion engine according to any one of claims 1 to 16, wherein a current is supplied to the starter when the starter is started so that the current supplied has a minimum magnitude required for a piston in a follower cylinder that follows the expansion-stroke-cylinder to exceed a top dead center of an compression stroke.

[Claim 18] The starting device for the internal combustion engine according to any one of claims 1 to 17, wherein the starter is started at such a timing that, when the starter is started and stopped after certain time but started second time because it is determined that the rotating state of the crank needs to restart the starter, a starting timing of the second time is adjusted such that the starter is coupled to the internal combustion engine during rotation of the crank.

[Detailed description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a starting device for an internal combustion engine.

[0002]

[Prior Art]

To start a known cylinder injection type internal combustion engine (hereinafter, "engine") that has cylinders with combustion chambers, which is at rest, fuel is injected and ignited into the

combustion chamber of a cylinder in an expansion stroke (hereinafter; "expansion-stroke-cylinder"). The fuel burns and produces combustion energy. The combustion energy is used to obtain the power to start the engine. However, the combustion energy alone is sometimes insufficient to start the engine. Various solutions have been proposed to solve this problem.

[0003]

Japanese Patent Application Laid Open No. 2002-4985 discloses the following starting device for a cylinder injection type internal combustion engine. When the engine is at rest, an expansion-stroke-cylinder is detected, and fuel is injected and ignited into the expansion-stroke-cylinder, to start the engine. Moreover, if the engine does not start because of insufficient combustion energy, a motor is used to assist the cranking to reliably start the engine.

[0004]

Patent Document 1:

Japanese Patent Application Laid Open No. 2002-4985

Patent Document 2:

Japanese Patent Application Laid Open No. 2002-39038

Patent Document 3:

Japanese Patent Application Laid Open No. 2002-4929

[0005]

[Problems to be Solved by the Invention]

According to technology disclosed in the above documents, the fuel is injected and ignited into the expansion-stroke-cylinder, and it is

determined whether the engine is going to start properly, and if the engine is not going to start, a starter is used to assist the starting of the engine. In other words, whether to use the starter is decided after confirming that the engine is not going start.

[0006]

However, because whether to use the starter is decided after confirming that the engine is not going to start, a time lag is produced between an optimal timing of starting of the starter and the real time of starting of the starter. As a result, sometimes the engine does not start.

[0007]

Such a time lag is to be eliminated, so that the starter can surely start the engine that ignites fuel in an expansion-stroke-cylinder.

[0008]

An object of the present invention is to provide the starting device for the internal combustion engine, capable of starting the starter at an optimal timing, allowing improved startability for ignition of fuel supplied to an expansion-stroke-cylinder.

Another object of the present invention is to provide the starting device for the internal combustion engine, in which shock caused by an engagement of gears is smaller, when the starter and the engine are engaged.

Yet another object of the present invention is to provide the starting device, in which energy consumed by the starter is reduced when the starter is started.

[0009]

[Means to Solve the Problems]

A starting device for an internal combustion engine according to the present invention ignites fuel supplied in an expansion-stroke-cylinder of the internal combustion engine to start the internal combustion engine, and includes a predicting unit that predicts a state of a crank when the expansion-stroke-cylinder is ignited, before a starter is started start, and a determining unit that determines whether to start the starter based on the state of the crank predicted.

[0010]

According to the present invention, it can be determined whether or not to start a starter at an earlier timing than in a method where the determination is made after the engine starts and the number of revolutions of the engine. The "fuel supplied in an expansion-stroke-cylinder" refers to fuel injected into cylinders of a direct injection engine, and fuel injected into an intake manifold of a port injection engine when the crank stops.

[0011]

In the starting device for the internal combustion engine according to the present invention, the predicting unit predicts a state of the crank before a first ignition is performed in the expansion-stroke-cylinder, and the determining unit determines whether the starter is to be started before the first ignition is performed in the expansion-stroke-cylinder.

[0012]

The ignition mentioned above includes to two objects: igniting fuel injected into cylinders of a direct injection engine; and igniting fuel injected into an intake manifold of a port injection engine when the crank stops. When the crank stops, the fuel injection in the port injection engine is performed when the internal combustion engine is not operating, i.e., at rest, before the predicting unit makes the prediction or the determining unit makes the determination.

[0013]

In the starting device for the internal combustion engine according to the present invention, the predicting unit estimates the state of the crank based on a stop position of the crank and a water temperature in the internal combustion engine.

[0014]

In the starting device for the internal combustion engine according to the present invention, the predicting unit estimates combustion power produced if the fuel in the expansion-stroke-cylinder is ignited, and predicts the state of the crank based on the combustion power estimated.

[0015]

In the starting device for the internal combustion engine according to the present invention, the predicting unit estimates an amount of oxygen in the expansion-stroke-cylinder and estimates the combustion power based on the amount of oxygen estimated.

[0016]

In the starting device for the internal combustion engine

according to the present invention, the predicting unit estimates the amount of oxygen based on a stop position of the crank corresponding to air capacity in the expansion-stroke-cylinder.

[0017]

In the starting device for the internal combustion engine according to the present invention, the predicting unit estimates air density in the expansion-stroke-cylinder, and estimates the amount of oxygen based on the air density estimated.

[0018]

In the starting device for the internal combustion engine according to the present invention, the predicting unit estimates the air density based on a water temperature in the internal combustion engine.

[0019]

In the starting device for the internal combustion engine according to the present invention, the predicting unit estimates frictional force produced if the fuel in the expansion-stroke-cylinder is ignited, and predicts the state of the crank based on both the frictional force estimated and the combustion power estimated.

[0020]

In the starting device for the internal combustion engine according to the present invention, the predicting unit estimates the frictional force based on friction produced when the crank rotates and a compression work in a follower cylinder that follows the expansion-stroke-cylinder.

[0021]

In the starting device for the internal combustion engine according to the present invention, the predicting unit estimates the frictional force based on a stop position of the crank that corresponds to the compression work in the follower cylinder.

[0022]

In the starting device for the internal combustion engine according to the present invention, the predicting unit estimates oil viscosity corresponding to the friction, and estimates the frictional force based on the oil viscosity estimated.

[0023]

In the starting device for the internal combustion engine according to the present invention, the predicting unit estimates the oil viscosity based on a water temperature in the internal combustion engine.

[0024]

In the starting device for the internal combustion engine according to the present invention, the state of the crank is either of a rotational angle of the crank or a number of revolutions of the internal combustion engine.

[0025]

In the starting device for the internal combustion engine according to the present invention, the starter is started after the fuel in the expansion-stroke-cylinder has been ignited.

[0026]

In the starting device for the internal combustion engine

according to the present invention, the starter is started at a timing such that the starter and the internal combustion engine get coupled to each other when the crank is in a state of acceleration.

[0027]

In the starting device for the internal combustion engine according to the present invention, a current is supplied to the starter when the starter is started so that the current supplied has a minimum magnitude required for a piston in a follower cylinder that follows the expansion-stroke-cylinder to exceed a top dead center of an compression stroke.

[0028]

In the starting device for the internal combustion engine according to the present invention, the starter is started at such a timing that, when the starter is started and stopped after certain time but started second time because it is determined that the rotating state of the crank needs to restart the starter, a starting timing of the second time is adjusted such that the starter is coupled to the internal combustion engine during rotation of the crank.

[0029]

In the present invention, the fuel is injected and ignited into the expansion-stroke-cylinder, to start the internal combustion engine. The predicting unit is provided to predict the state of the crank without starting the starter, before the fuel is initially injected. Based on the state of the crank predicted, the starter is controlled to start or not to start.

[0030]

According to the present invention, it can be predicted whether it is necessary to start the starter before fuel injection. Therefore, even if the starting time of the starter is delayed, the starter can start at an optimal timing.

[0031]

The present invention relates to operating the cylinder direct injection gasoline engine by directly injecting fuel into cylinders of the engine and igniting the fuel by generating a spark. When the engine is at rest, a stop position of a crank is detected to decide whether the cylinder is an expansion-stroke-cylinder, and the fuel is injected into the expansion-stroke-cylinder and the fuel is ignited after a lapse of a predetermined vaporization period, to restart the engine. The present invention has the following characteristics, (1) to (6).

[0032]

(1) Before starting the engine, an amount of a cranking of the crank due to the initial combustion of the fuel in the expansion-stroke-cylinder is predicted from a temperature of coolant in the engine (or state of air in the cylinder, or air density) and the stop position of the crank. Moreover, it is determined whether a piston of the follower cylinder that follows the expansion-stroke-cylinder, exceeds a top dead center (hereinafter, "TDC") of a compression stroke by only the initial combustion, based on the amount of the cranking predicted. If the amount of the cranking is such that the initial combustion is insufficient to cause the piston of the follower cylinder to exceed the

TDC of the compression stroke, a starter motor is started after the crank starts to rotate due to the initial combustion.

[0033]

(2) The starter motor in (1) is started as follows. Before the engine is started, the number of revolutions of the engine by the initial combustion in the expansion-stroke-cylinder and the changes in the number are predicted based on the water temperature (or state of air in the cylinder, or air density) and the stop position of the crank. Based on the result of prediction, the operation starting timing of the starter motor is set so that the starter motor and the engine are engaged with each other in a period during which the rotation of the engine is accelerated by the initial combustion.

[0034]

(3) Before starting the engine, it is possible to predict the number of revolutions of the engine and the changes in the number based on the water temperature (or state of air in the cylinder, or air density) and the stop position of the crank. Based on the prediction, it is determined whether the piston of the follower cylinder that follows the expansion-stroke-cylinder exceeds the TDC of the compression stroke by only the initial combustion. If it is determined that the piston of the follower cylinder that follows the expansion-stroke-cylinder does not exceed the TDC of the compression stroke by only the initial combustion, the starter motor is started after the crank is operated by the initial combustion.

[0035]

(4) The starter motor in (3) is started as follows. Based on the prediction results of (3), the starter motor is started at a timing such that the starter and the engine get coupled to each other, during the period which the rotation of the engine is accelerated by the initial combustion.

[0036]

(5) An energizing time of the starter motor is determined as a minimum amount required for the piston of the following cylinder, which follows the cylinder in which initial combustion is performed (expansion-stroke-cylinder), to exceed the TDC of the compression stroke.

[0037]

(6) The number of revolutions of the engine is detected in (1) to (5). Based on the detection results, when it is determined that after the piston of the following cylinder (second cylinder), which follows the cylinder in which initial combustion is performed (expansion-stroke-cylinder), exceeds the TDC of the compression stroke, a piston in a third cylinder that follows the second cylinder does not exceed the TDC of the compression stroke, the starter motor is restarted.

[0038]

(7) In (6), the starter motor is restarted while the crank is operating, and the energizing time of the starter motor is determined as a minimum amount required for the piston of the third cylinder to exceed the TDC of the compression stroke.

[0039]

(8) The operations of (6) and (7) are repeated until the engine is started so as to operate by itself.

[0040]

[Embodiments of the Invention]

Embodiments according to the present invention are explained in detail below with reference to the accompanying drawings. The present invention is not limited to following embodiments.

[0041]

(First Embodiment)

The present embodiment relates to operating a cylinder direct injection gasoline engine (hereinafter, "engine") by directly injecting fuel into cylinders of the engine and igniting the fuel by generating a spark. The engine is started in the following manner. That is, when the engine is at rest, a stop position (or a rotational angle position) of a crank (or crankshaft) in each cylinder is detected to decide whether the cylinder is an expansion-stroke-cylinder, and the fuel is injected into the expansion-stroke-cylinder and the fuel is ignited after a lapse of a predetermined vaporization period. Subsequently, fuel is injected into a cylinder (hereinafter, "follower cylinder") that follows the expansion-stroke-cylinder and the fuel is ignited when a piston of the follower cylinder exceeds a top dead center (hereinafter, "TDC") of a compression stroke by an initial combustion in the expansion-stroke-cylinder. Subsequently, the fuel in the cylinders that follow the follower cylinder is successively is ignited. This process

causes the fuel in the cylinders to ignite one after the other and start the engine.

[0042]

In the present embodiment, before starting the engine, an amount of a cranking of the crank due to the initial combustion of the fuel in the expansion-stroke-cylinder (hereinafter, "initial combustion") is predicted from a temperature of coolant in the engine (or state of air in the cylinder, or air density) and the stop position (stop angle) of the crank. Moreover, if the amount of the cranking is such that the initial combustion is insufficient to cause the piston of the follower cylinder to exceed the TDC of the compression stroke, a starter motor is started after the crank starts to rotate due to the initial combustion.

[0043]

To start the engine without assistance from an external power, it is essential that the piston of the follower cylinder exceeds the TDC of the compression stroke by the initial combustion to cause a second combustion of the fuel in the follower cylinder (hereinafter, "second combustion") and combustion of the fuel in the cylinders thereafter.

[0044]

Whether the piston of the follower cylinder is going to exceed the TDC can be determined from (1) combustion power and (2) frictional force. The inventers of the present invention obtained the following findings as a result of a series of experiments and hard work. The findings are explained below with reference to Fig. 8.

[0045]

(1) Combustion Power

The combustion power produced is proportional to the amount of oxygen in the cylinder. The amount of oxygen depends on (a) air capacity of the cylinder and (b) air density in the cylinder. The air capacity of the cylinder depends on the stop position of the crank. The air density in the cylinder can be obtained from a temperature of the coolant (hereinafter, "water temperature") in the engine. If the water temperature is high, the air density in the cylinder shall be low. At a particular stop position of the crank, the amount of oxygen in the cylinder is proportional to the air density in the cylinder, so the combustion power drops as the water temperature rises.

[0046]

(2) Frictional Force

The frictional force is proportional to (c) friction due to viscosity of a lubricating oil and (d) compression work in the follower cylinder. The friction due to the viscosity of the lubricating oil is troublesome mainly in a valve operating system, and the Inventors found that a specific relationship exists between the friction due to the viscosity and temperature of the oil in the engine (which is generally same as the water temperature). The Inventors also found that a specific relationship exists between the compression work in the follower cylinder and the stop position of the crank.

[0047]

Fig. 3 is a graph that illustrates how the cranking torque of the engine changes with the water temperature. The cranking torque

required to start the engine is minimum when the water temperature is in a half warmed state, that is, when the water temperature is at around A °C. More cranking torque is required to start the engine when the water temperature is above or below A °C.

[0048]

The oil temperature lowers if the water temperature is below A °C, and accordingly the viscosity of the oil (viscosity coefficient) increases, which leads to increased friction. Thus, if the water temperature is below A °C, the cranking torque is higher.

[0049]

The viscosity of the oil drops as the water temperature rises above A °C to cause a lubricating surface to change from a fluid phase to a solid phase (oil film breakage), and thereby the friction increases. Thus, if the water temperature is above A °C, the cranking torque is higher.

[0050]

Fig. 3 relates to a case when the number of revolutions of the crank is lower than those during a normal operation (i.e., when the engine is at rest or almost at rest). During the normal operation the number of revolutions is high so that oil film breakage occurs when the water temperature is above A °C. A graph that illustrates how the cranking torque of the engine changes with the water temperature during normal operation can be obtained by horizontally shifting the curve in Fig. 3 towards right.

[0051]

Because the present embodiment relates to starting of an engine and the engine rotates slowly while stating than during the normal operation, the graph in Fig. 3 relates to the present embodiment. When the engine rotates slowly, the lubricating oil is hard to slide between the surfaces of the cylinder and the piston so that oil film breakage occurs when the water temperature is around A °C.

[0052]

Fig. 4 is a graph that illustrates how the air density in the cylinder changes with temperature. The air density is inversely proportional to the temperature. The amount of oxygen in the air decreases as the air density decreases at high temperature. The combustion power decreases as the amount of the oxygen in the air decreases.

[0053]

Fig. 1 is a graph of experimental results that illustrate how the rotational angle of a crank changes in the expansion-stroke-cylinder by an initial combustion with the water temperature. In other words, Fig. 1 illustrates experimental results on how the rotational angle of the crank (°CA) in the expansion-stroke-cylinder changes due to the initial combustion in the expansion-stroke-cylinder.

[0054]

The characteristic as shown in Fig. 1 are obtained due to the change in the friction, which is explained with reference to Fig. 3, and the change in the combustion power, which is explained with reference to Fig. 4.

[0055]

In the present embodiment, data in Fig. 1 about water temperature and rotational angle of the crank was acquired and mapped previously at each stop position of the crank. The data for the rotational angle of the crank includes data for combustion power and frictional force. In other words, data for the rotational angle of the crank, the combustion power, and the frictional force was acquired in the experiment. When the engine is to be started, by referring to the map, it is determined, from the stop position of the crank and the water temperature, whether the engine will start without the assistance of the starter.

[0056]

In the experiment, an inline six-cylinder type engine was targeted in which crank angles of adjacent cylinders were displaced by 120 degrees CA with respect to each other. In Fig. 1, a stop position B means an angle of the crank of an expansion-stroke-cylinder, i.e., stop position of the crank.

[0057]

Fig. 1 corresponds to a case in which a stop position of the expansion-stroke-cylinder is the stop position B. Consequently, the stop position of the crank of the follower cylinder, which is displaced by 120 degrees with respect to the expansion-stroke-cylinder, is (B−120) degrees. In other words, to satisfy the condition that the piston of the follower cylinder exceeds the TDC of the compression stroke, the rotational angle of the crank in the expansion-stroke-cylinder due to the

initial combustion in the expansion-stroke-cylinder has to be (120−B) degrees or higher. Whether the rotational angle of the crank in the expansion-stroke-cylinder due to the initial combustion is (120−B) degrees or higher is determined by referring to the map (Fig. 1). From the map, it can be understood that, when the water temperature is between C °C and D °C, the rotational angle of the crank in the expansion-stroke-cylinder due to the initial combustion is (120−B) degrees or higher. In other words, if the water temperature is between C °C and D °C, the piston of the follower cylinder shall exceed the TDC of the compression stroke.

[0058]

Therefore, if the water temperature of the engine is between C °C and D °C, it is determined that the engine can be started without the starter. On the other hand, if the water temperature is lower than C °C or higher than D °C, it is determined that the starter is required to assist the starting of the engine.

[0059]

It can be noticed in Fig. 1 that the rotational angle of the crank rapidly decreases when the water temperature is around D °C. This happens because the piston of the follower cylinder exceeds the TDC of the compression stroke when the water temperature is at around D °C. When the water temperature is at around D °C, even a slight change in the combustion power and the frictional force causes an abrupt change in the rotational angle of the crank. Therefore, in order to ensure a safety margin, it may be determined that the starter is not

required to assist the starting of the engine if the water temperature is a little lower than D °C.

[0060]

Thus, as described above, the stop position of the crank of the follower cylinder is obtained from the stop position of the crank of the expansion-stroke-cylinder, and from the stop position obtained, the rotational angle of the crank of the expansion-stroke-cylinder required for the piston of the follower cylinder to exceed the TDC of the compression stroke (for starting the engine without external-power assistance) is obtained.

[0061]

Experiments are conducted with an engine to previously obtain the graph shown in Fig. 1 at each stop position of cranks (Fig. 2) in each cylinder, and the data is mapped. By referring to the map, the rotational angle of the crank by the initial combustion in the expansion-stroke-cylinder can be obtained based on the stop position of the crank for the expansion-stroke-cylinder and the water temperature. The rotational angle of the crank, that is, a predicted rotational angle of the crank by initial combustion in the expansion-stroke-cylinder is obtained by referring to the map. If the rotational angle of the crank is larger than the rotational angle of the crank required for the piston in the follower cylinder to exceed the TDC of the compression stroke, it is determined that the engine can be started without external assistance.

[0062]

On the contrary, if the predicted rotational angle of the crank by the initial combustion in the expansion-stroke-cylinder is smaller than the rotational angle of the crank required for the piston in the follower cylinder to exceed the TDC of the compression stroke, it is determined that the external assistance is necessary to start the engine.

[0063]

Whether the predicted rotational angle is smaller or larger than the rotational angle of the crank required for the piston in the follower cylinder to exceed the TDC of the compression stroke can be determined even before staring the engine so that the starter can be starting at an optimal timing.

[0064]

If the stop positions of the crank representing the air capacity of the cylinder and the compression work in the follower cylinder are the same as each other (Fig. 8 and Fig. 9), the rotational angle of the crank due to the initial combustion can be predicted by the water temperature representing the air density and the oil viscosity. Note that the information in Fig. 9 is rewritten from the relation in Fig. 8, centering on the stop position of the crank and the water temperature.

[0065]

If the stop position of the crank changes, the amount of compression work in the follower cylinder and the air capacity in the cylinder change to cause the rotational angle of the crank by the initial combustion to change.

[0066]

Fig. 2 is a graph of data in cases where the stop positions of the crank are the stop position B, the TDC side of the stop position B, and the before top dead center (BTDC) side of the stop position B. A relation between the water temperature and the rotational angle of the crank according to respective stop positions of the clank is previously measured to prepare a map. The rotational angle of the crank can be predicted based on the water temperature and the stop position of the crank by referring to the map. It is thereby possible to predict whether the piston of the follower cylinder can exceed the TDC of the compression stroke only by the initial combustion based on the predicted rotational angle of the crank.

[0067]

As shown in Fig. 2, different stop positions of the crank require uses of different thresholds (water temperature) to determine whether the position in the follower cylinder can exceed the TDC of the compressing stroke only by the initial combustion.

[0068]

Although it is mentioned here to obtain the air density and the oil viscosity from the water temperature as shown in Fig. 8 and Fig. 9, the air density and the oil viscosity may be obtained using other parameter(s) or may be obtain using the water temperature and other parameter(s).

[0069]

For example, the other parameters include, for example, the time duration (hereinafter, "leaving time") for which the engine is in the

a stop state. The temperature distribution immediately after the engine is stopped is narrow because a coolant is cycled along a water gallery of the engine so that the temperature in the cylinder (cylinder temperature) is not very different from the temperature of the coolant (coolant temperature) measured with a temperature sensor. However, due to the radiation of heat, the cylinder temperature differs from the coolant temperature with the leaving time. Moreover, due to evaporation of residual fuel during the leaving time, the air density also varies with leaving time.

[0070]

Therefore, although the water temperatures detected by the temperature sensor of two engines are the same, but if the leaving times are different, the air densities and the oil viscosities shall be different. Therefore to obtain better results, it is preferable that data is measured and mapped for each leaving time. On the other hand, the data may be multiplied by a constant of proportionality that depends on the leaving time to obtain data that corresponds to the leaving time.

[0071]

Fig. 5 is a flowchart of an operation of the present embodiment.

At step S1, it is determined whether there is fuel pressure of a predetermined value or higher (fuel pressure: residual pressure) in the side of delivery pipe (fuel passage).

[0072]

Pressure is applied to fuel by an electric pump in the port injection engines. However, it is difficult to inject the fuel into a

cylinder using the pressure by the electric pump so that a mechanical pump is used when in the direct injection engines (cylinder injection type internal combustion engines). The mechanical pump is started in response to starting of the engine to apply the pressure to the fuel. In other words, in the direct injection engines, pressure is not applied to the fuel when the engine is at rest.

[0073]

On the other hand, in the present embodiment, when the engine is stopped for a short time such as an idling stop in an economy running system, it is assumed that the residual pressure remains in the delivery pipe. As explained above, only when the fuel pressure remains in the direct injection engine, it is possible to send the fuel by the fuel pressure and inject the fuel into the expansion-stroke-cylinder. That is why presence or absence of the residual pressure is determined at step 1.

[0074]

If it is determined that the residual pressure is less than the predetermined value ("No" in step S1), the engine is started normally, using only the starter, i.e., without performing the fuel injection and ignition in the expansion-stroke-cylinder (step S2). Because, as the residual pressure in the expansion-stroke-cylinder is insufficient, it is impossible to rotate the crank satisfactorily even if the fuel injection and ignition are performed.

If it is determined that the residual pressure is equal to or higher than the predetermined value ("Yes" in step S1), the system control

passes to step S3.

[0075]

At step S3, the rotational angle of the crank by initial combustion in the expansion-stroke-cylinder is predicted based on the water temperature and the stop position of the crank using the map with the data of Fig. 2 registered therein.

[0076]

At step S4, it is determined whether the water temperature is between E °C and F °C. If the water temperature is too low, i.e., less than E °C, or the water temperature is too high, i.e., higher than F °C, as shown in Fig. 1, the crank cannot be made to rotate satisfactorily even if the fuel injection and ignition are performed in the expansion-stroke-cylinder.

[0077]

If the water temperature is not between E °C and F °C ("No" in step S4), the engine is started using only the starter, i.e., without performing the fuel injection and ignition in the expansion-stroke-cylinder (step S2).

If the water temperature is between E °C and F °C ("Yes" in step S4), the system control passes to step S5.

[0078]

The graph of the water temperature in Fig. 1 can be roughly divided into three areas. A first area corresponds to a case when the water temperature is not between E °C and F °C. A second area corresponds to a case where the water temperature is between E °C

and F °C but the rotational angle of the crank is short although the crank is made to rotate by the initial combustion so that assistance of the starter is required. A third area corresponds to a case where the water temperature is between E °C and F °C and the crank rotates until the piston in the follower cylinder exceeds the TDC of the compression stroke only by the initial combustion so that assistance of the starter is not required.

[0079]

At step S5, it is predicted whether the piston in the follower cylinder exceeds the TDC of the compression stroke only by the initial combustion in the expansion-stroke-cylinder. This prediction is performed based on the rotational angle of the crank predicted at step S3 and the rotational angle of the crank required for the piston in the follower cylinder, detected from the stop position of the crank, to exceed the TDC of the compression stroke.

[0080]

If the piston in the follower cylinder can exceed the TDC of the compression stroke only by the initial combustion in the expansion-stroke-cylinder ("Yes" at step S5), the engine is started only by performing fuel injection and ignition in the expansion-stroke-cylinder, i.e., without using the starter (step S7).

[0081]

If the piston in the follower cylinder cannot exceed the TDC of the compression stroke only by the initial combustion in the expansion-stroke-cylinder ("No" in step S5), the engine is started both

by performing fuel injection and ignition in the expansion-stroke-cylinder and using the starter (step S6).

[0082]

It is also possible to previously measure the number of revolutions of the engine caused by the initial combustion in the expansion-stroke-cylinder and the changes in the number to prepare them as a map in the same manner as that of the rotational angle of the crank. Therefore, it is possible to predict the number of revolutions and the changes in the number based on the stop position of the crank and the water temperature. Such a map will be explained later as a second embodiment of the present invention.

[0083]

Thus, it is possible to determine whether the piston in the follower cylinder exceeds the TDC of the compression stroke by the initial combustion, that is, whether starter assist is required, by detecting the water temperature and the stop position of the crank before the engine is started. This scheme provides advantages as follows.

[0084]

Generally, the starter motor requires a large current for the starting, and therefore, the starter motor is not directly energized, but a magnet switch is turned on by a starter relay to energize the starter motor. Consequently, the starter motor is largely delayed in starting (response delay). The delay in starting ranges from about 0.1 to about 0.3 second. If it is determined whether the starter is required to start

after the engine is started and the starter is made to start in response to the result of determination, the optimal starting time may be missed.

[0085]

In the present embodiment, however, it is possible to decide whether the starter is required before the engine is started. Therefore, even if the starter has some delay in starting, the starter can be made to start (the starter is energized) at the optimal timing by taking into account the delay time. Thus, it is possible to improve the startup performance by the initial combustion in the expansion-stroke-cylinder.

[0086]

Furthermore, because the rotational angle of the crank and/or the number of revolutions of the engine and the changes in the number are predicted before starting of the engine, the starter can be made to start accordingly. Therefore, it is possible to optimally control the starter.

[0087]

Moreover, if it is determined that the starter is required to start, the starter is not activated to start the engine when it is at rest, as in conventional cases, but is activated to further accelerate the engine already rotating by the initial combustion in the expansion-stroke-cylinder. Therefore, the current consumption is reduced. This has been confirmed in the testing of Fig. 6 explained later.

[0088]

It has been explained above to determine based on both (1) the

combustion power and (2) the frictional force whether the piston in the follower cylinder exceeds the TDC of the compression stroke by the initial combustion. However, if the combustion power is strong enough, the determination can be performed based on only the magnitude of the combustion power, regardless of frictional force.

[0089]

The direct injection engine has been explained in the embodiment described above, but the present invention is also applicable to a port injection engine. For cranking of the port injection engine, fuel is previously injected into an intake manifold when the crank stops, and at the following step, only ignition is required to rotate the crank. As explained above, for starting the port injection engine, the fuel is injected into the intake manifold when the port injection engine is at rest and an electric pump is used for fuel supply. Therefore, the step of checking the fuel pressure (step S1) of Fig. 5 is not performed, but the engine status is predicted based on the water temperature and the stop position of the crank, the water temperature is checked, and whether the starter is required to start is determined based on the predicted rotational angle of the crank by referring to the map (steps S3 to S5).

[0090]

(Second embodiment)

A second embodiment of the present invention is explained below with reference to Fig. 7.

[0091]

The operation of the second embodiment is performed based on the operation of the first embodiment. That is, data (not shown) for the water temperature, the number of revolutions of the engine by the initial combustion in the expansion-stroke-cylinder, and for the changes in the number is previously acquired at each stop position of the crank, and the acquired data is mapped.

[0092]

If it is determined that the starter is required to start in the manner explained in the first embodiment, a starting timing of the starter motor is obtained for starting the engine by referring to the map prepared in the second embodiment.

[0093]

Before the engine is started, the number of revolutions of the engine by the initial combustion in the expansion-stroke-cylinder and the changes in the number are predicted based on the water temperature and the stop position of the crank by referring to the map. Based on the result of prediction, the operation starting timing of the starter motor is set so that the starter motor and the engine are engaged with each other in a period during which the rotation of the engine is accelerated by the initial combustion.

[0094]

It is desirable that the starter motor and the engine are engaged with each other when a difference between their rotational speeds is small. This is because noise produced through engagement between gears of the two and abrasion of the gears can be reduced. The

operation starting timing of the starter is controlled (sometimes even the rotational speed is controlled) so as to synchronize to the timing of engaging the gears with each other, that is, to make the rotational speed of the starter identical to that of the engine at the same time or to make smaller the difference between the rotational speeds.

[0095]

The starter is engaged with the engine while accelerating the starter. Therefore, it is desirable that the engine is also engaged with the starter when the rotation of the engine is accelerated by the initial combustion.

[0096]

Fig. 7 is a graph of a temporal change in crank speed by the initial combustion in the expansion-stroke-cylinder and in starter speed. The rotational speed is plotted on the y-axis and the time is plotted on the x-axis.

[0097]

The rotational speed of the crank indicated by a line 10 is accelerated by the initial combustion to attain a predetermined speed and drops thereafter. The data for the changes in the rotational speed of the crank as indicated by the line 10 is registered in the map through the previous measurement.

As shown in Fig. 7, a period during which the crank speed is increasing is an acceleration period 11, and a period during which it is decreasing is a deceleration period 12.

[0098]

Lines 13a to 13c of Fig. 7 indicate rotational speeds of the starter motor, respectively. The lines 13a to 13c have a different point from one another only in a starting timing of the starter motor.

[0099]

As explained above, the starter and the engine are engaged with each other desirably when a difference between their rotational speeds is small. Therefore, the crank and the starter are engaged with each other (gears of the two are engaged with each other) when the rotational speed of the crank indicated by the line 10 is equal to each of the rotational speeds of the starter indicated by the respective lines 13a to 13c.

[0100]

After the starter is engaged with the crank, the crank is accelerated by the starter because the rotational speed of the starter is faster. In other words, if the crank is engaged with the starter started at the timing indicated by the line 13a, the rotational speed of the crank changes as indicated by a line 11a. Likewise, if the crank is engaged with the starter started at the timing indicated by the line 13b, the rotational speed of the crank changes as indicated by a line 11b. Furthermore, if the crank is engaged with the starter started at the timing indicated by the line 13c, the rotational speed of the crank changes as indicated by a line 11c.

[0101]

If the change (acceleration) in the rotational speed of the crank is smaller before and after the engagement with the starter, the shock

caused by the engagement is smaller, and noise and abrasion caused by the engagement of the gears are smaller. Of the changes indicated by the lines 11a to 11c, the change indicated by the line 11a causes the smallest shock, while the change indicated by the line 11c causes the largest shock.

[0102]

The starter is engaged with the engine while accelerating. Therefore, the starter is desirably engaged with the engine when the rotation of the engine is accelerated by the initial combustion (the acceleration period 11) because the shock caused by the engagement is reduced.

[0103]

As explained above, the timing of starting the starter needs to be controlled according to the timing of starting the engine by the initial combustion. However, in order to prevent delay in starting of the starter, it is required to generate a signal to make the starter start before the engine is started by the initial combustion. In the conventional technology, it is determined whether the starter assist is required after the engine is started. Therefore, the starter cannot be started at the optimal timing.

[0104]

(Third Embodiment)

In a third embodiment of the present invention, an energizing time of the starter motor, in the first and second embodiments, is determined as a minimum amount required for the piston of a following

cylinder, which follows the cylinder in which initial combustion is performed (expansion-stroke-cylinder), to exceed the TDC of the compression stroke. If the piston of the follower cylinder exceeds the TDC of the compression stroke, there is no need for starter assist any more, and therefore, the energizing time is set accordingly.

[0105]

When ignition is performed in the follower cylinder, new traction is generated, which allows the starter assist to be stopped. In the example, it is adequate that the starter assist is kept only until the crank in the follower cylinder is moved (120−A) degrees and exceeds the TDC of the compression stroke. Therefore, the energizing time of the starter motor is set to an amount corresponding to the amount of starter assist. As explained above, it is possible to determine whether the starter assist should be stopped based on the position of the crank, that is, whether the crank is rotated (120−A) degrees.

[0106]

Fig. 10 is a graph of temporal change in a current (starter current) passing in the starter motor when the starter starts the engine when the engine is at rest, as is conventionally performed.

[0107]

As shown in Fig. 10, the engagement of the starter with the engine causes the starter motor to decelerate, and thereby the starter current abruptly drops and slightly increases right after the drop (refer to P).

[0108]

After the engagement with the engine, the starter current vibrates vertically just like being wavy a plurality of times. When the starter current is increasing it means that the engine is in the compression stroke to cause the load to increase (Q). When the starter current is decreasing it means that the piston exceeds the TDC of the compression stroke to cause the load to decrease (R). At R, the engine is in the expansion stroke, and the engine is accelerated by the combustion power to be once disengaged from the starter, and accordingly, the gears are disengaged.

[0109]

At S where the starter current has decreased to the low level and starts increasing again, the engine enters into the compression stroke to cause the engine speed to be decreased. As a result, the engine is engaged with the starter again.

[0110]

In the present embodiment, the fuel injection and ignition are performed in the expansion-stroke-cylinder to cause the crank to start its rotation, and the starter is engaged with the crank while accelerating. This point is different from the conventional method of engaging the starter with the crank when it is at rest and starting the rotation of the crank. However, as shown in Fig. 10, the temporal change in the starter current after the starter is engaged with the engine (the curve after P) is the same as that of the present embodiment.

[0111]

As explained above, in the present embodiment, the energizing

time of the starter motor is set so that the starter assist is performed until the piston in the follower cylinder exceeds the TDC of the compression stroke but is not performed after the piston has exceeded the TDC. Therefore, in the present embodiment, energization of the starter may be stopped at a timing t1 at which the current exceeds a peak of the current at Q, indicating that the piston exceeds the TDC of the compression stroke in Fig. 10. As explained above, it is possible to determine the timing at which the starter assist is to be stopped based on the temporal change in the starter current.

[0112]

Fig. 6 is a graph of behaviors of the starter current and the rotation of the crank at the time of starting the engine.

Reference numeral 21 represents temporal change in the rotational angle of the crank in the present embodiment, and reference numeral 22 represents temporal change in the rotational angle of the conventional crank. Reference numeral 23 represents temporal change in current values of the starter current in the present embodiment, and reference numeral 24 represents temporal change in current values of the starter current in the conventional technology.

[0113]

As shown in Fig. 6, conventionally, after the current starts to pass through the starter (22s), the starter causes the rotation of the crank when it is at rest to start (22a). The rising edge of 22a matches the timing of a peak 24a of a line 24. This indicates that the gears are engaged with each other to cause the rotation of the crank to start. At

this moment, a large current temporarily passes through the starter. An area of 24b indicates that the load is so large that the piston exceeds the TDC of the compression stroke, and 24c indicates that the load is small because of the expansion stroke. An area of 24d indicates that the load is large because of a next compression stroke.

[0114]

On the other hand, in the present embodiment, the current starts to pass through the starter (23s), at the timing at which the crank starts to rotate (21a) and acceleration has started. Note that the magnitude of the current that starts to pass through the starter is the same as that in the conventional technology (22s and 23s).

[0115]

In the present embodiment, because the starter is engaged with the crank accelerated while the starter is accelerating, the load applied to the starter at the time of engagement is not large at all. This prevents excess current to be passed through the starter.

[0116]

A point of 23e indicates a timing at which the energization of the starter is stopped. Before the point 23e, there is a portion indicating that the load increases in the compression stroke, and that the current value increases and then exceeds the TDC of the compression stroke, and that the load decreases and the current value starts to decrease. The point 23e is a timing at which the starter current starts to decrease. As explained above, it is determined whether the starter assist is stopped based on the temporal change in the starter current.

[0117]

In the present embodiment, the starter is engaged with the crank accelerated while the starter is accelerating, and therefore, the timing at which the piston exceeds the TDC is earlier (23e and 24b) than that of the conventional method. Under the same condition, the energizing time of the conventional starter is slightly shorter than one second while the energizing time of the starter in the present embodiment can be suppressed to G seconds (23e).

[0118]

As explained above, there are two methods: the method of determining the stopping based on the position of the crank and the method of determining the stopping based on the change in the current value passing through the starter. In addition, the energizing time can be set as a predetermined time after the starter is started, considering that the starting of the starter when it is at rest may be delayed. In other words, when the starter is to be stopped is determined based on the position of the crank, it is first detected that the crank is positioned at a predetermined angle (120−A degrees in the above example) and then the starter is stopped. It should be noted that the starter actually stops after a delay time in the starting elapses from the time when a stop signal is sent to the starter. In this method, an actual energizing time may sometimes exceed the required minimum time.

[0119]

Therefore, the rotational angle of the crank corresponding to the energizing time of the starter is previously measured to obtain the

results of measurement as a map. In other words, in the example, an energizing time of the starter in order to obtain the rotational angle of the crank of (120−A) degrees is obtained from the map. Therefore, by energizing the starter only that time, it is possible to suppress the energizing time to the required minimum without influence of delay in the starting.

[0120]

By the above methods, it is possible to reduce the energizing time of the starter to a required minimum time, and to reduce power consumption.

[0121]

(Fourth Embodiment)

If the second combustion in the follower cylinder that follows the cylinder with the initial combustion has failed or if the combustion power of the combustion in the follower cylinder is not adequate, combustions in the cylinder thereafter cannot take place, and thereby it is sometimes impossible to start the engine. In a fourth embodiment of the present invention, when it is determined, using the technique of the first to third embodiments, that the piston in a third cylinder (hereinafter, "third cylinder) that follows the follower cylinder does not exceed the TDC of the compression stroke after the piston in the follower cylinder that follows the cylinder with the initial combustion exceeds the TDC of the compression stroke, the starter motor is started.

[0122]

Concretely, it is determined whether the piston in the third

cylinder exceeds the TDC of the compression stroke by detecting the rotational speed or the number of revolutions of the engine, or the rotational acceleration of the engine.

[0123]

In the present embodiment, two cases can be considered before the starter motor is started in order that the piston of the third cylinder exceeds the TDC of the compression stroke. As one case, the piston in the follower cylinder that follows the cylinder with initial combustion exceeds the TDC of the compression stroke only by the initial combustion without starting of the starter. As second case, the piston in the follower cylinder exceeds the TDC of the compression stroke by assisting the initial combustion with the starter.

[0124]

In the present embodiment, as specifically explained in the third embodiment, the energization of the starter is stopped once when the piston of the follower cylinder has exceeded the TDC of the compression stroke. However, if it is determined thereafter that the piston of the third cylinder does not exceed the TDC of the compression stroke, the starter motor is made to restart.

[0125]

According to the present embodiment, the engine can be started even if no combustion occurs in the follower cylinder or if the combustion power is not adequate.

Furthermore, according to the present embodiment, the energizing time of the starter can be reduced to a minimum time, which

allows reduction in power consumption, as compared with the conventional starting method of keeping the starter energized until the starting is complete.

[0126]

(Fifth embodiment)

In the fourth embodiment, the starter motor is started for the third cylinder during rotation of the crank, and the energizing time of the starter motor is determined as a required amount for the piston in the third cylinder to exceed the TDC of the compression stroke. In the present embodiment of the present invention, this is realized in the same manner as that of the third embodiment.

[0127]

The fifth embodiment of the present invention provides advantageous as explained below.

Lesser current is consumed because the starter is engaged with the engine rotating.

Lesser shock is caused when the gears engage with each other, and therefore, both noise and abrasion are kept at a low level.

Reduction in power consumption becomes possible because the energizing time of the starter can be reduced to minimum.

[0128]

(Sixth embodiment)

In a present embodiment, each operation of the fourth and the fifth embodiments is performed until the engine can operate by itself without assistance of an external power. In the present embodiment,

the determination is made by detecting the rotational speed or the number of revolutions of the engine or the rotational acceleration of the engine.

[0129]

The present embodiment provides advantageous as explained below.

The engine can be started even if no combustion takes place in the third cylinder and the cylinders thereafter.

The energizing time of the starter is reduced to minimum, which allows reduced power consumption, as compared with that of the conventional starting method in which the starter is kept energized until the starting is complete.

[0130]

[Effects due to the Invention]

According to a starting device for an internal combustion engine according to the present invention, a starter is started at an optimal timing, which allows improved startability for ignition of fuel supplied to an expansion-stroke-cylinder.

[Brief Description of the Drawings]

[Fig. 1] A graph that illustrates how a rotational angle of a crank changes in an expansion-stroke-cylinder by an initial combustion with water temperature, which is to be input to a map used for an embodiment according to the present invention.

[Fig. 2] A graph that illustrates how the rotational angle of the crank changes in the expansion-stroke-cylinder by the initial

combustion with a stop position of the crank, which is to be input to the map used for the embodiment according to the present invention.

[Fig. 3] A graph that illustrates how a cranking torque of the engine changes with water temperature.

[Fig. 4] A graph that illustrates how air density in the cylinder changes with temperature.

[Fig. 5] A flowchart of an operation of according to an embodiment of the present invention.

[Fig. 6] A graph of behaviors of a starter current and a rotation of the crank at a time of starting the engine, according to an embodiment of the present invention and conventional technology.

[Fig. 7] A graph illustrating the start timing of the starter according to an embodiment of the present invention.

[Fig. 8] A diagram illustrating elements to predict a rotational angle of the crank according to an embodiment of the present invention.

[Fig. 9] A diagram illustrating elements obtained by detected elements according to an embodiment of the present invention.

[Fig. 10] A graph of temporal change in a current passing in the starter motor when the starter engages with the engine.

[Description of Signs]

21 Change of rotational angle of crank according to the present embodiment

22 Change of rotational angle of crank in a conventional case

23 Change of current values according to the present embodiment

24 Change of current values in a conventional case

P	When engaged with engine
Q	When exceeding a top dead center of an compression stroke
R	Expansion stroke
S	Compression stroke

[Type of Document] Abstract

[Abstract]

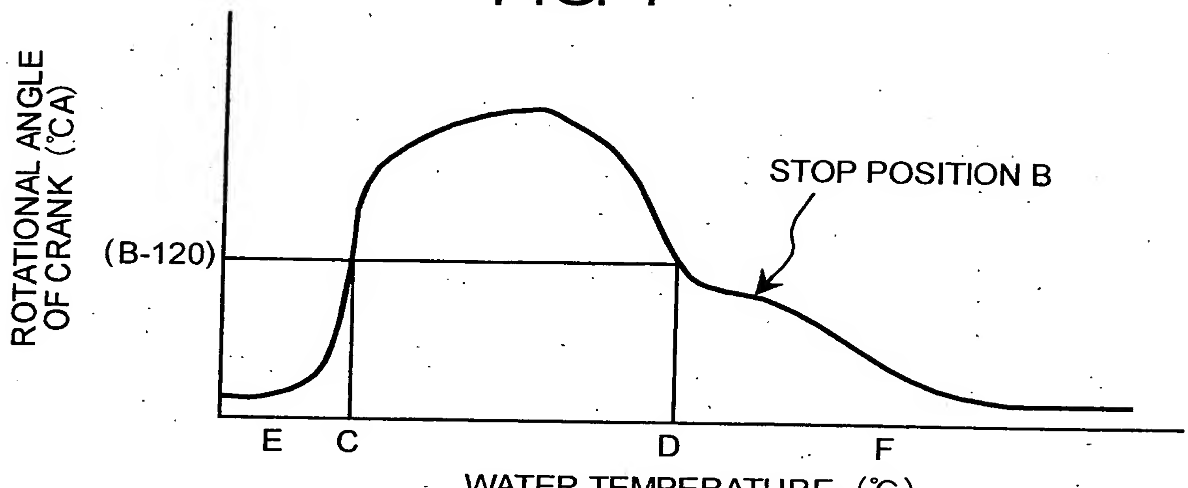
[Object] To provide a starting device for an internal combustion engine capable of starting a starter at an optimal timing, which allows improved startability for ignition of fuel supplied to an expansion-stroke-cylinder.

[Means] A starting device for an internal combustion engine that ignites fuel supplied in an expansion-stroke-cylinder of the internal combustion engine to start the internal combustion engine, including a predicting unit that predicts a state of a crank of the cylinders if the expansion-stroke-cylinder is ignited when a starter does not start, and a determining unit that determines whether to start the starter to based on the state of the crank predicted.

[Selected Figure] Fig. 2

[TYPE OF DOCUMENT] DRAWING

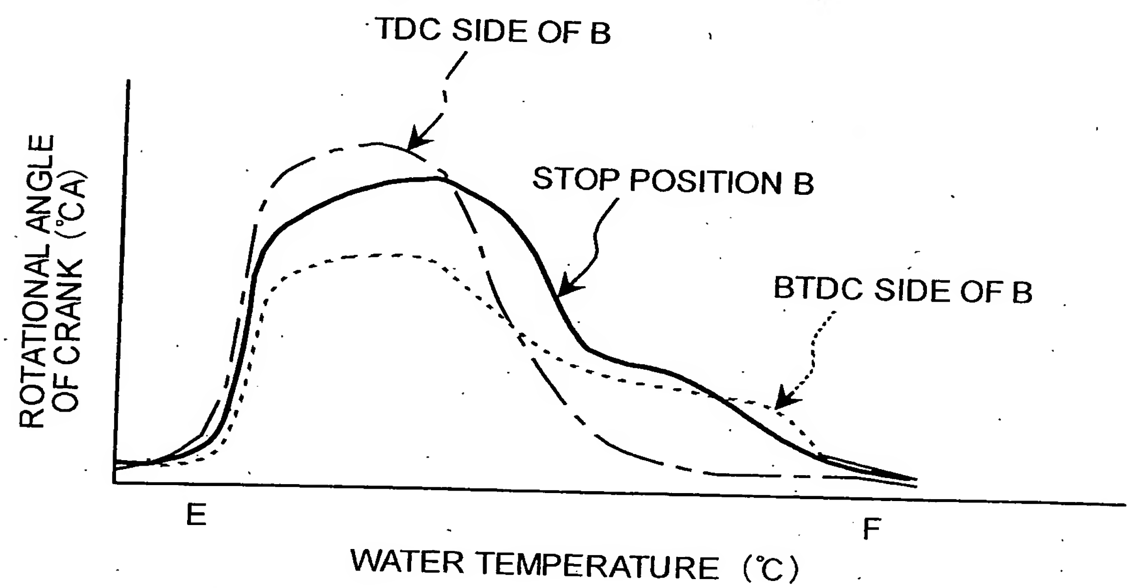
FIG. 1



CHANGE IN ROTATIONAL ANGLE OF CRANK IN EXPANSION-STROKE-CYLINDER BY INITIAL COMBUSTION (WITH WATER TEMPERATURE)

FIG. 2

CHANGE IN ROTATIONAL ANGLE OF CRANK WITH STOP POSITION OF CRANK



CHANGE IN ROTATIONAL ANGLE OF CRANK IN EXPANSION-STROKE-CYLINDER BY INITIAL COMBUSTION

FIG. 3

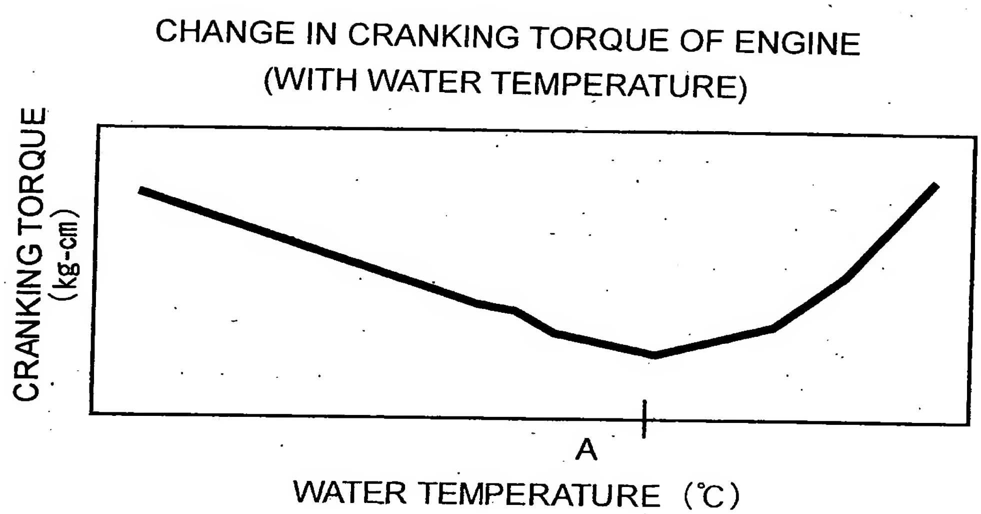

CHANGE IN CRANKING TORQUE OF ENGINE
(WITH WATER TEMPERATURE)
CRANKING TORQUE
(kg-cm)
A
WATER TEMPERATURE (℃)

FIG. 4

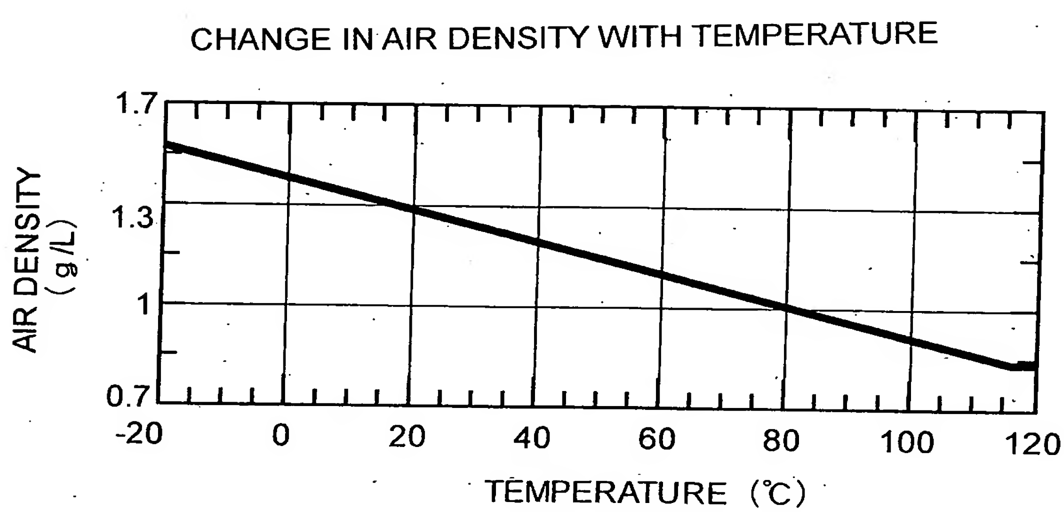

CHANGE IN AIR DENSITY WITH TEMPERATURE
AIR DENSITY
(g/L)
1.7
1.3
1
0.7
-20
0
20
40
60
80
100
120
TEMPERATURE (℃)

FIG. 5

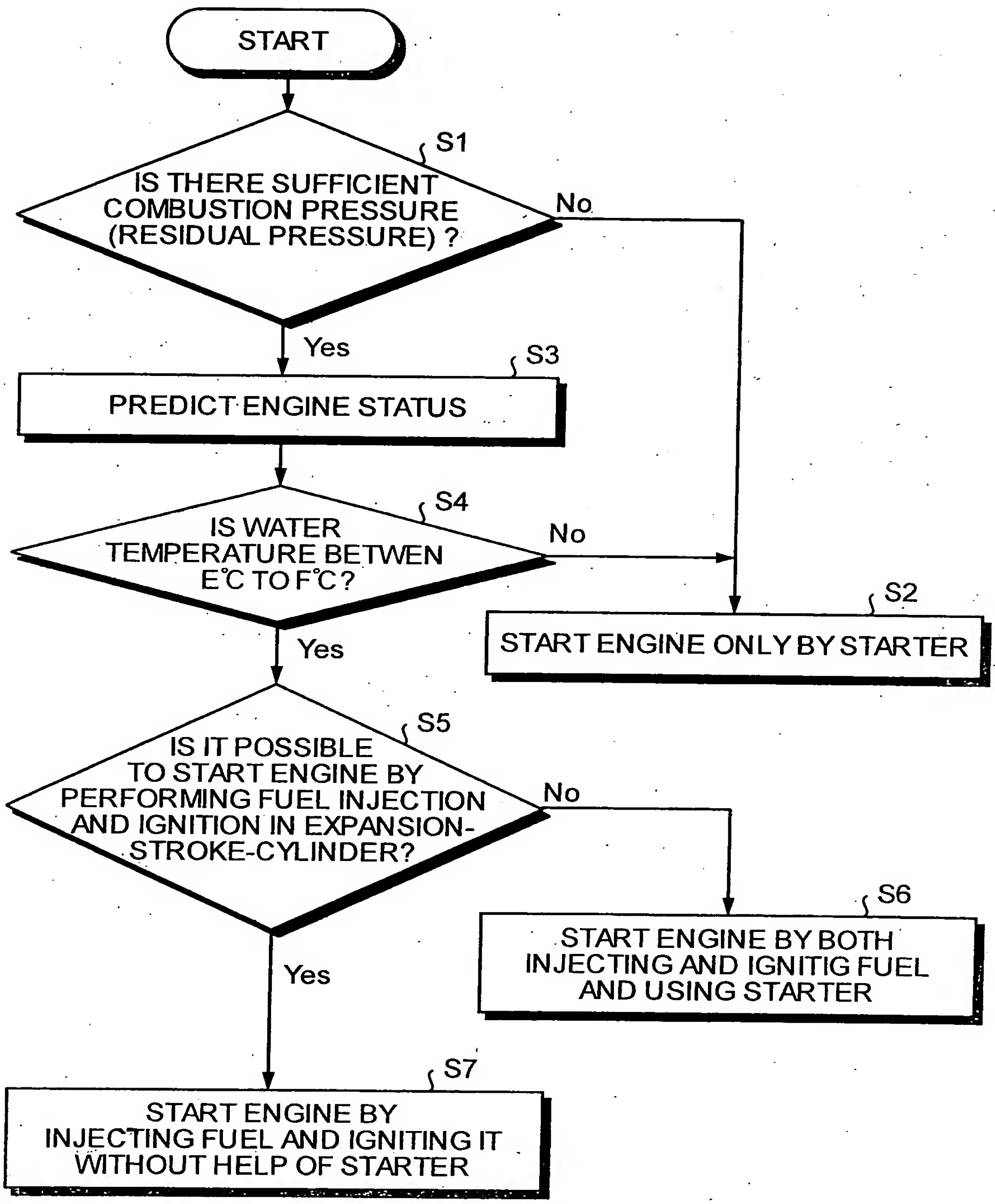

START
S1
IS THERE SUFFICIENT COMBUSTION PRESSURE (RESIDUAL PRESSURE) ?
No
Yes
S3
PREDICT ENGINE STATUS
S4
IS WATER TEMPERATURE BETWEN E℃ TO F℃ ?
No
S2
START ENGINE ONLY BY STARTER
Yes
S5
IS IT POSSIBLE TO START ENGINE BY PERFORMING FUEL INJECTION AND IGNITION IN EXPANSION-STROKE-CYLINDER?
No
S6
START ENGINE BY BOTH INJECTING AND IGNITIG FUEL AND USING STARTER
Yes
S7
START ENGINE BY INJECTING FUEL AND IGNITING IT WITHOUT HELP OF STARTER

FIG. 6

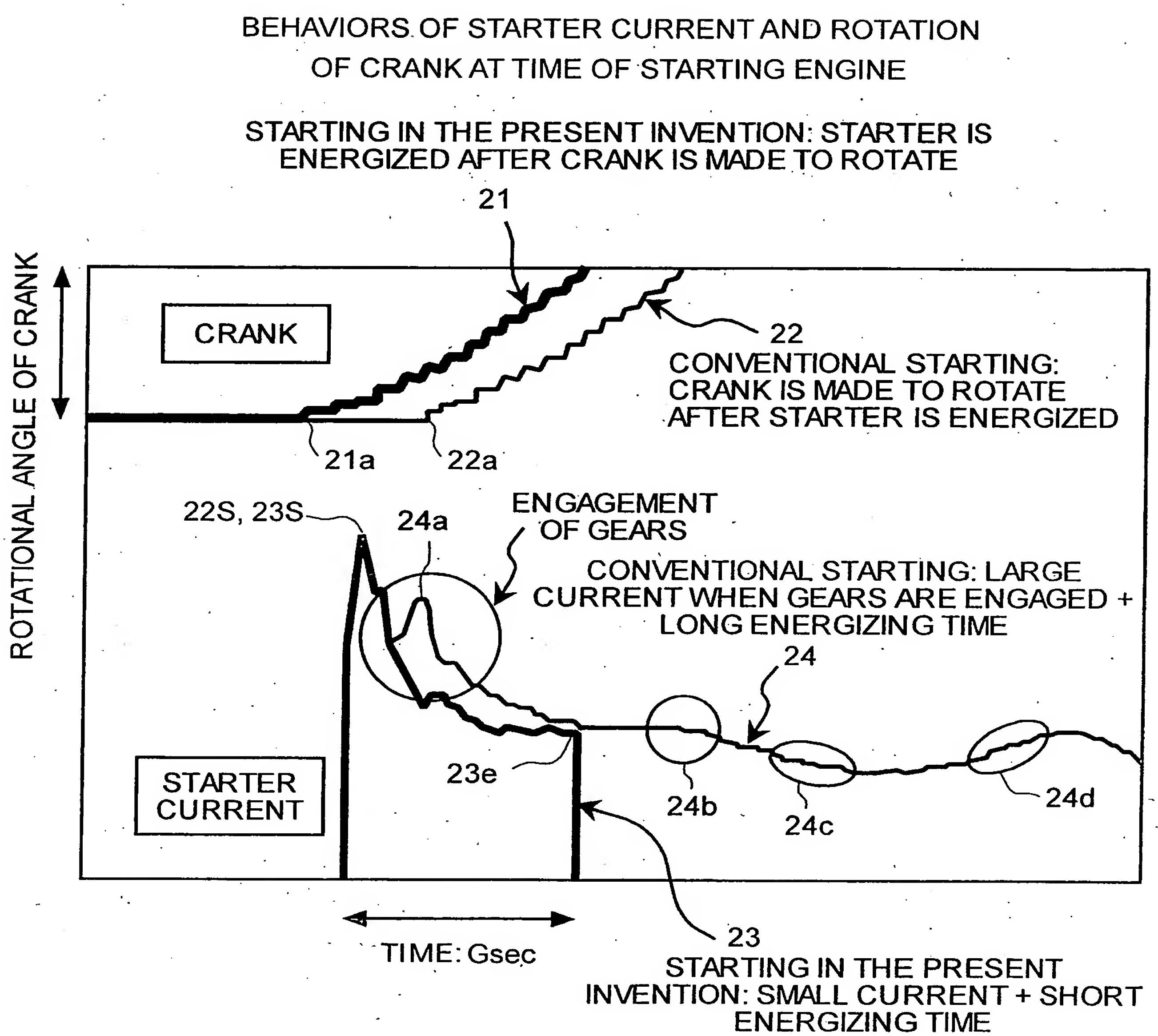

BEHAVIORS OF STARTER CURRENT AND ROTATION OF CRANK AT TIME OF STARTING ENGINE
STARTING IN THE PRESENT INVENTION: STARTER IS ENERGIZED AFTER CRANK IS MADE TO ROTATE
21
ROTATIONAL ANGLE OF CRANK
CRANK
22
CONVENTIONAL STARTING: CRANK IS MADE TO ROTATE AFTER STARTER IS ENERGIZED
21a
22a
22S, 23S
24a
ENGAGEMENT OF GEARS
CONVENTIONAL STARTING: LARGE CURRENT WHEN GEARS ARE ENGAGED + LONG ENERGIZING TIME
24
STARTER CURRENT
23e
24b
24c
24d
TIME: Gsec
23
STARTING IN THE PRESENT INVENTION: SMALL CURRENT + SHORT ENERGIZING TIME

FIG. 7

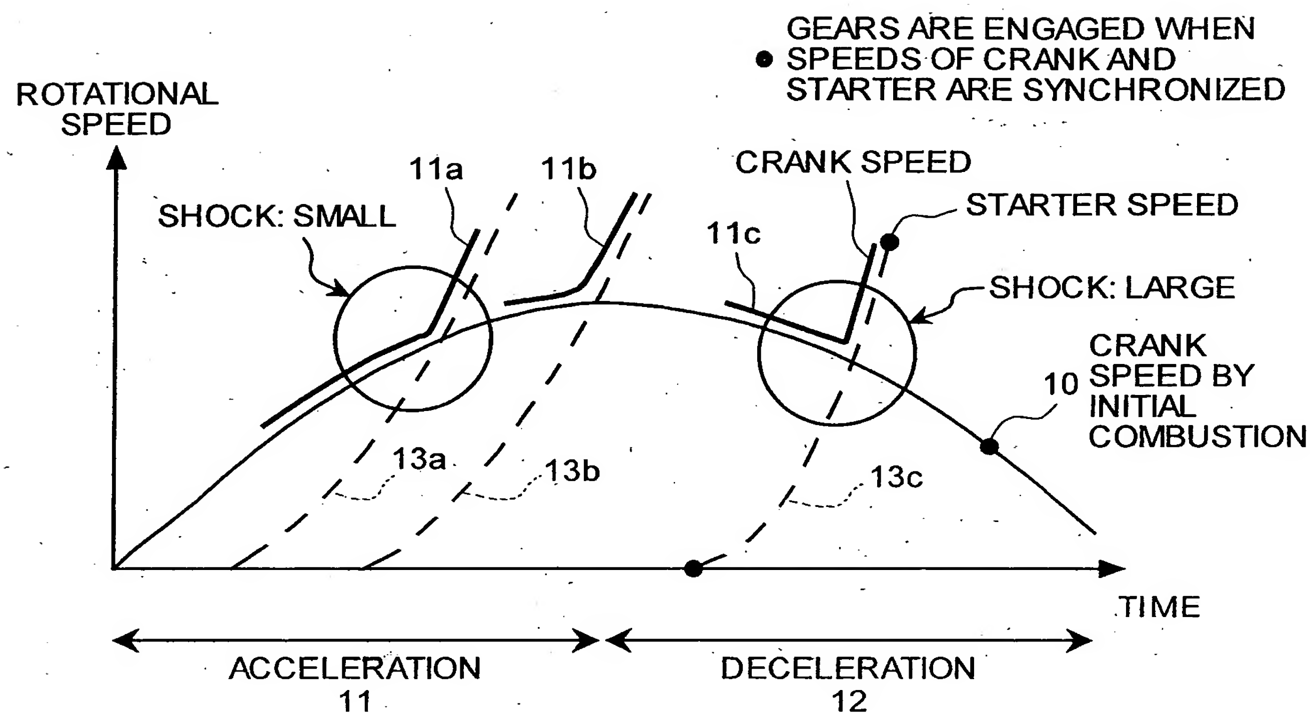


FIG. 8

(1)COMBUSTION POWER — AMOUNT OF OXYGEN IN CYLINDER
- (a)AIR CAPACITY OF CYLINDER —STOP POSITION OF CRANK
- (b)AIR DENSITY IN CYLINDER —WATER TEMPERATURE

(2)FRICTIONAL FORCE
- (c)FRICTION —OIL TEMPERATURE (WATER TEMPERATURE)
- (d)COMPRESSION WORK—STOP POSITION OF CRANK

FIG. 9

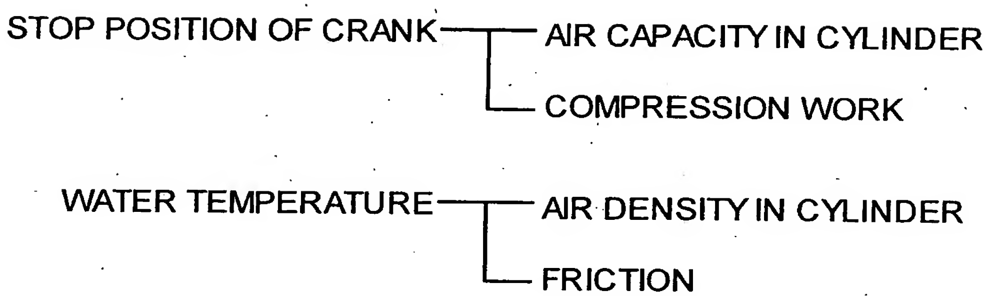
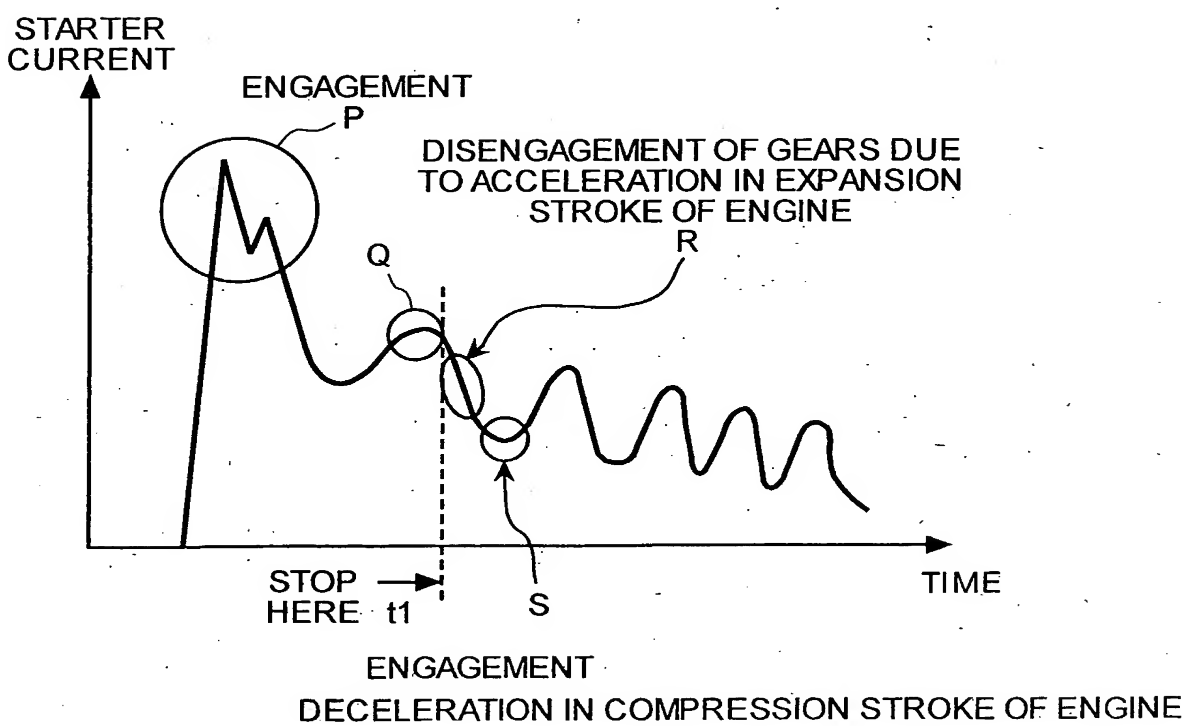

STOP POSITION OF CRANK
AIR CAPACITY IN CYLINDER
COMPRESSION WORK
WATER TEMPERATURE
AIR DENSITY IN CYLINDER
FRICTION

FIG. 10


STARTER CURRENT
ENGAGEMENT
P
DISENGAGEMENT OF GEARS DUE TO ACCELERATION IN EXPANSION STROKE OF ENGINE
Q
R
STOP HERE t1
S
TIME
ENGAGEMENT
DECELERATION IN COMPRESSION STROKE OF ENGINE